1-MC TRANSISTOR NOISE-FIGURE TESTER

By Larry Blaser

I. INTRODUCTION

The noise-figure tester described in this paper is an accurate direct-reading instrument intended for either production testing or device evaluation and characterization. The tester, which has a constant-bandwidth controlled-gain amplifier, measures the noise figure of NPN and PNP transistors over a wide range of source resistance and collector current. It is completely self contained. Typical 1-mc contours of constant spot-noise figure for the 2N918 taken with this tester are shown in Fig. 1.

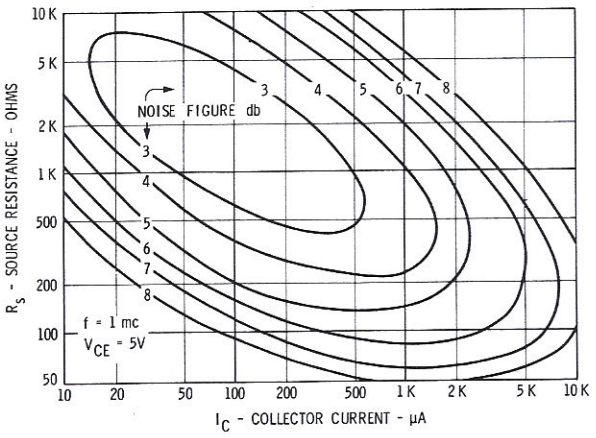

FIG. 1. Constant contours of 1-mc spot noise figure for a 2N918.

Previous 1-mc noise-figure measurements have conventionally been carried out by using a temperature-limited diode as a calibrated noise source. [1, 2] Accurate measurements are obtainable with this method, but the equipment setup is often cumbersome and because the read-out is not direct, measurement time is long.

This tester, in addition to its primary function of measuring transistor noise figure, can be used to measure the noise figure of 1-mc tuned amplifiers or of broadband (video) amplifiers. Because the instrument is direct reading, amplifiers can easily be optimized for best noise performance by making circuit modifications and adjustments while monitoring the noise figure.

II. MEASUREMENT METHOD

The theory of the basic method of noise-figure measurement which is used in this 1-mc tester is described elsewhere. [3] It requires that the gain and equivalent noise bandwidth of an amplifier be known. The amplifier gain is controlled by an agc network which is made dependent on the source resistance in such a manner that the output noise voltage is a direct function of the noise figure of the tester amplifier. The bandwidth is determined by a passive filter in the amplifier. Because the first stage of the amplifier is a low-noise circuit containing the transistor-under-test and the second stage contributes little noise, the measured noise figure is essentially that of the transistor-under-test. [4]

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The 1-mc noise originating in the amplifier-input circuit is converted to an audio noise and passed through a bandwidth-determining filter. A pilot signal, introduced at the amplifier input, is used to establish the overall gain. The spectrum of these signals is shown in Fig. 2.

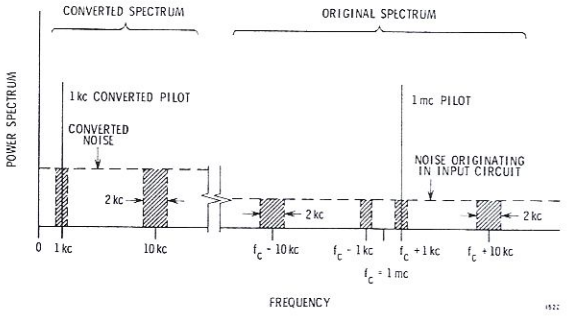

FIG. 2. Power spectrum diagram.

A block diagram of the tester is shown in Fig. 3. The transistor-under-test is the first transistor of a three-transistor broadband amplifier which feeds a 1-mc tuned amplifier having a range of over 50 db. The output of the 1-mc amplifier is mixed with a 1000-kc signal from a crystal-controlled oscillator and the difference frequencies are amplified by the audio amplifier. The 10-kc filter passes the noise voltages originating from the thermal noise of the source resistance and from the excess noise added by the transistor-under-test at frequencies which are centered at 10 kc on either side of 1 mc.

A 1001-kc pilot signal from a second crystal-controlled oscillator is supplied through an attenuator to the input stage and, along with noise, is amplified and mixed with the 1000-kc signal. The difference frequency is separated from the noise in the 1-kc filter. The 1-kc difference frequency and the output from the 1001-kc crystal-controlled oscillator are held equal in magnitude by the comparator, which supplies a correction signal to the tuned 1-mc, agc amplifier. The overall amplification of the thermal noise of the source resistance is, therefore, determined solely by the attenuation network between the 1001-kc crystal-controlled oscillator and the input and by the gain of the 1-kc and 10-kc filters. Because the noise which appears at the output of the 10-kc filter originates in two frequency bands 10 kc on either side of 1 mc, and because these two noise sources are uncorrelated, the equivalent noise bandwidth of the amplifier is twice the power bandwidth of the 10-kc filter.

Knowing the equivalent noise bandwidth, the voltage gain and the source resistance of an amplifier, the noise figure as a function of output noise voltage has been shown to be (Ref. 3):

$$NF = 20 \log \frac{\sqrt{\overline{e_{no}^2}}}{A\sqrt{4kTBR_s}} \qquad (1)$$

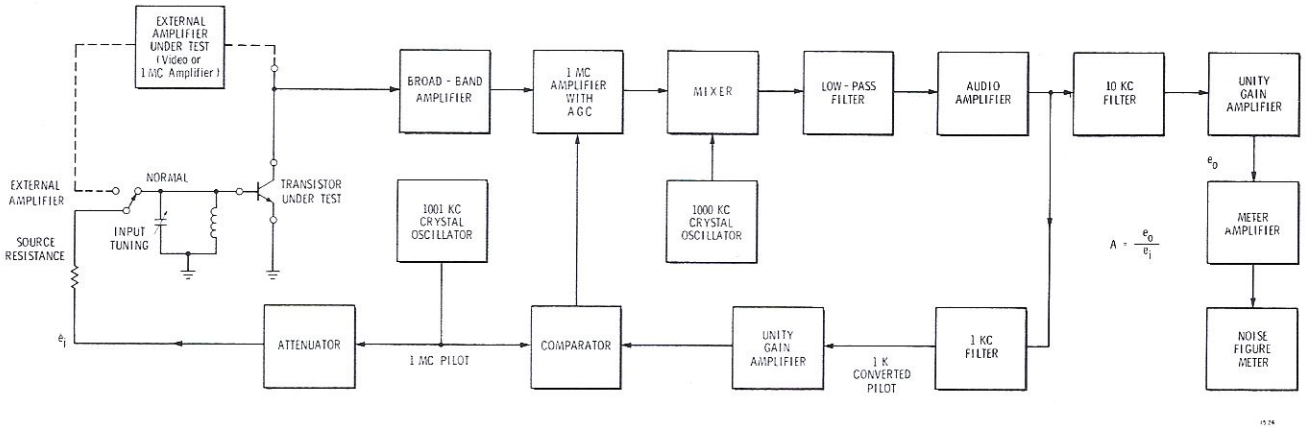

FIG. 3. Block diagram of 1-mc noise-figure tester.

where

NF = noise figure expressed in db.

$\sqrt{\overline{e_{no}^2}}$ = total rms noise voltage at the output.

$A = \frac{e_o}{e_1}$ = voltage gain (See Figure 3).

k = Boltzmann's constant

$= 1.38 \times 10^{-23} \frac{\text{watt-sec}}{°K}$

T = absolute temperature - °K.

B = equivalent noise bandwidth - cps.

R_s = source resistance - ohms.

The temperature, T, is assumed to be 300°K (27°C), a normal laboratory ambient temperature. The voltage gain, A (See Fig. 3 and Fig. 4), is a measured value which, by appropriate programming of the pilot amplitude, is made to vary inversely as the square root of the source resistance, so the quantity, $A\sqrt{4kTBR_s}$, is constant for all values of R_s. The gain of the meter amplifier is adjusted so that the meter, calibrated in db, reads 0 db with a noise voltage, $A\sqrt{4kTBR_s}$, at the output of the 10-kc filter. With a transistor-under-test, the meter reads the output noise voltage, $\sqrt{\overline{e_{no}^2}}$, in db above $A\sqrt{4kTBR_s}$. This db reading is the noise figure of the transistor-under-test.

III. CIRCUIT DESCRIPTION

The complete schematic diagram of the tester is shown in Fig. 4 (on last page fold-out). The transistor-under-test, Q_1, is measured in the common-emitter configuration. The base is externally tunable with a capacitor for minimum noise figure. The untuned collector of Q_1 drives the low input impedance feedback pair, Q_7 and Q_8.

Diodes D_{10} and D_{11} are inserted to prevent the broadband amplifier from breaking into oscillation when Q_1 is inserted into the test socket.

Transistors Q_9 and Q_{10} are agc-type transistors[5, 6], which exhibit a gradual decrease in h_{fe} with increasing collector current. Forward agc of Q_{10} and delayed forward agc of Q_9 provide more than 50 db reduction in gain in the 1-mc tuned amplifier stage. The bandwidth of the amplifier is about 100 kc at -3 db so that the gain variation between 1 kc and 10 kc from the center frequency is less than 0.2 db.

The output voltages of the agc stage and of the 1000-kc oscillator are added and applied to the base of the mixer transistor, Q_{11}. The difference outputs from the mixer are fed through the low-pass filter to the audio amplifier stage of Q_{15}, Q_{16}, and Q_{17}, which in turn drives the 1-kc and 10-kc filters.

The 10-kc filter has a power bandwidth determined by R_1, and the gain is determined by R_2 and R_3. The output of the 1-kc filter is passed through a high-input-impedance unity-gain amplifier which drives one input of the comparator.

In the comparator the two input signals, 1 kc and 1001 kc, are rectified and the resulting d-c voltages are applied to the high-gain, d-c differential amplifier, Q_{26} through Q_{29}. The agc correction voltage, developed in the collector of Q_{28}, is fed to the Darlington amplifier output stage, Q_{24} and Q_{25}.

The crystal-controlled oscillators are identical except for the crystal frequencies so that only one need be described. Referring to the 1000-kc oscillator, Q_5 is the oscillator transistor. Tuning in the collector of Q_5 provides a fine frequency adjustment. The signal in the collector circuit is sampled by Q_4, which establishes a constant amplitude of about 1 volt rms to the emitter-follower output, Q_6, by controlling the base current of Q_5.

The noise voltage is measured by an average-reading-type meter circuit which is calibrated in decibels with 0 db corresponding to the rms noise voltage, $A\sqrt{4kTBR_s}$. (The use of an average reading meter to measure rms noise is discussed in

Refs. 7. and 8.) The meter circuit consists of a unity-gain amplifier, Q_{20} and Q_{21}, which drives Q_{22}, a high-impedance source for meter rectifiers D_{17} and D_{18}. Q_{23} is the d-c current source with a very high a-c impedance to the collector of Q_{22} so that all the a-c current flows in the meter rectifiers. The current through the meter is limited to about 120 μA by heavy forward conduction of diode D_{19} at voltages over 0.6 volts. The meter scale conversion to decibels is given in Table I.

TABLE I

Decibel Scale		Meter Current
Range 0 - 10 db	Range 10 - 20 db	μA
0	10	15.9
1	11	17.8
2	12	20.0
3	13	22.4
4	14	25.1
5	15	28.2
6	16	31.6
7	17	35.5
8	18	39.8
9	19	44.7
10	20	50.1

IV. OPERATING INSTRUCTIONS

1. Calibrate the instrument as shown in Section V.
2. Insert the test transistor and adjust the bias conditions.
3. Set S_1 for the desired source resistance.
4. Adjust C_1 for minimum reading on the noise figure meter.
5. Read NF directly in db.

V. CALIBRATION

1. Adjust regulated power supplies to +24 V and -24 V.
2. Insert a low-noise, vhf transistor, e.g., a Fairchild 2N918, in the test socket and adjust the bias conditions for V_{CE} = 5 V and I_C = 1 mA.
3. Set S_1 to the 1 kΩ position.
4. Connect a d-c voltmeter to the output of the comparator, TP 2.
5. Adjust the two crystal-controlled oscillators for a difference frequency of 1 kc by tuning for a maximum voltage at TP 2. The absolute frequency of each oscillator is not critical, but they should, however, be operated close to their specified frequencies of 1001 kc and 1000 kc for maximum stability.
6. Tune the 1-mc amplifier for a maximum voltage at TP 2.
7. Connect a d-c voltmeter across the inputs of the differential amplifier of the comparator, TP 3 and TP 4.
8. Adjust the comparator balance for zero volts between TP 3 and TP 4.
9. Place S_4 in the test position and apply a 1-kc signal to TP 1. Adjust the amplitude of this signal for a 1-volt output from the 1-kc filter, TP 5.
10. Note the amplitude of the signal at TP 1 obtained in the previous step, place S_4 in the "calibrate" position, and apply a 10-kc signal of the same amplitude to TP 1.
11. Place S_5 in the 0 - 10 db position.
12. Adjust the 10-kc gain and bandwidth controls for a meter reading of 10 db (full scale) with a power bandwidth of 2 kc. This is most easily accomplished by varying R_1 and R_3 until the response curve in Fig. 5 is duplicated.

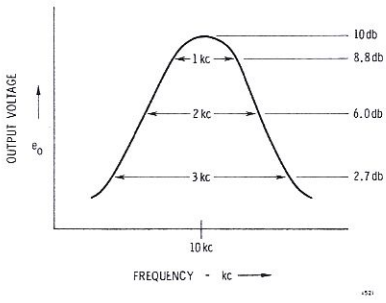

FIG. 5. 10-kc filter response curve.

13. Place S_5 in the 10 - 20 db position and adjust R_2 for a reading of 10 db in this range.
14. Disconnect from the tester all equipment used in the calibration procedure. Place S_4 in the normal position.

VI. CONSTRUCTION

In the layout of the tester r-f techniques are required. It is essential that the 1001-kc oscillator be well shielded to prevent radiation into the input stage. Although radiation shielding of the 1000-kc oscillator is not required, it is nevertheless desirable so that it will have drift characteristics similar to the 1001-kc oscillator, thus keeping a fixed 1-kc difference frequency. All inductors and transformers in the input stage and the 1-mc amplifier require shielding to prevent regeneration and instability. The outside metal cover of the instrument acts as an overall shield. In areas of high interference normally encountered outside of a screen room an r-f cover must, in addition, be provided for the transistor-under-test.

Component selection is not critical except for the 1 per cent resistors in the gain-determining circuits. If carbon or metal-film resistors in the range of 10Ω to 3 KΩ are used (in parallel or series combinations to obtain resistance values outside of this range), the reactive component at 1 mc can be ignored and 1 per cent values measured at d-c are satisfactory.

VII. ACCURACY

The accuracy of the tester is affected by the factors in Equation (1) and by the noise contribution of the second stage. Because the second stage is very low noise, its noise contribution is negligible except when the transistor-under-test is operated at a very low collector current and has little gain. If the tester is properly constructed and calibrated, its accuracy under most operating conditions is within ± 1 db.

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ACKNOWLEDGEMENT

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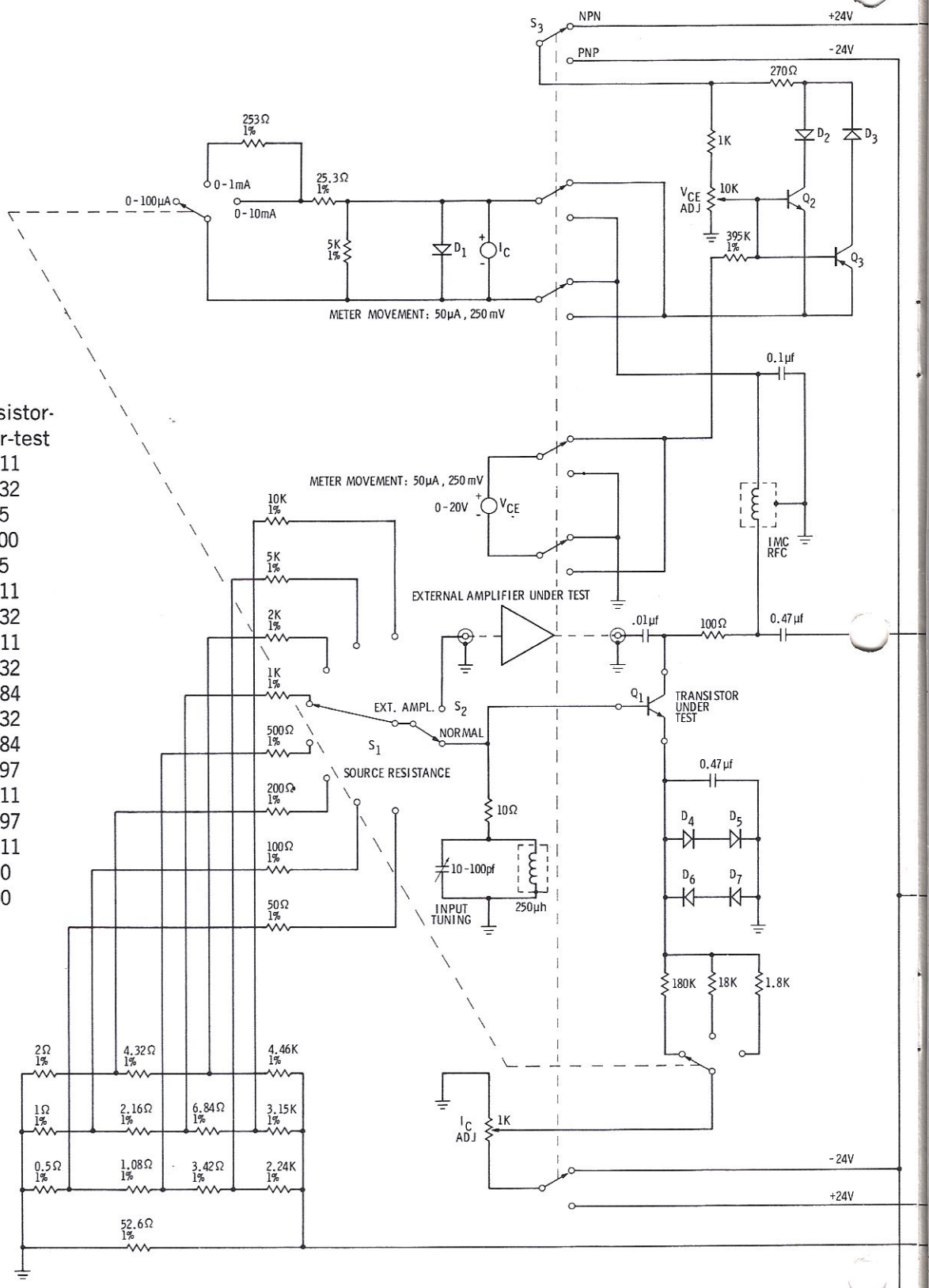
PARTS LIST

Q_1	Transistor-under-test
Q_2	2N1711
Q_3	2N1132
Q_4 through Q_8	2N915
Q_9, Q_{10}	FT0000
Q_{11} through Q_{14}	2N915
Q_{15} through Q_{18}	2N1711
Q_{19}	2N1132
Q_{20}	2N1711
Q_{21}, Q_{22}	2N1132
Q_{23} through Q_{25}	2N2484
Q_{26}	2N1132
Q_{27} through Q_{29}	2N2484
Q_{30}	2N2297
Q_{31}, Q_{32}	2N1711
Q_{33}	2N2297
Q_{34}, Q_{35}	2N1711
D_1 through D_{22}	FD100
D_{23} through D_{30}	FD200



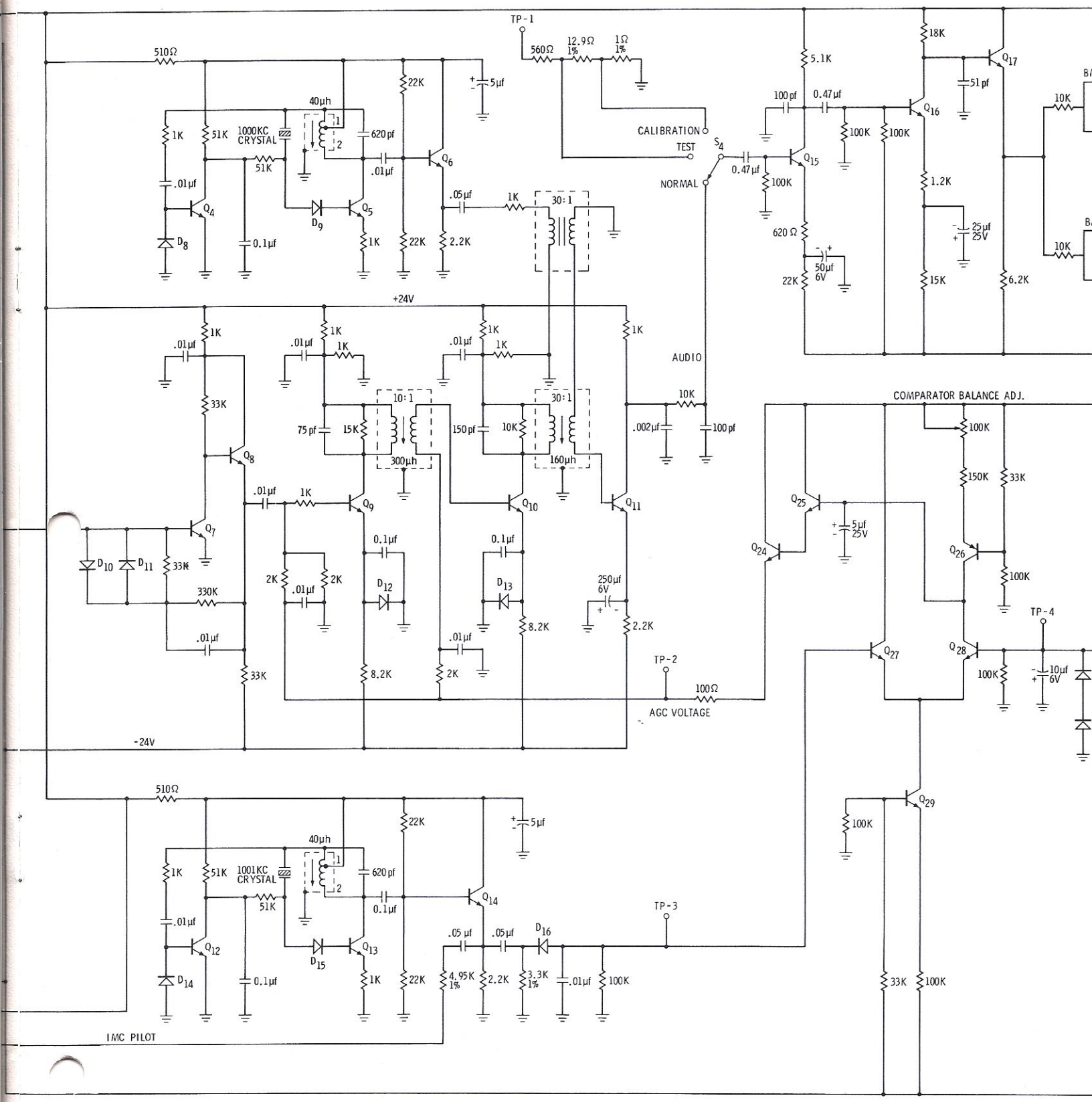
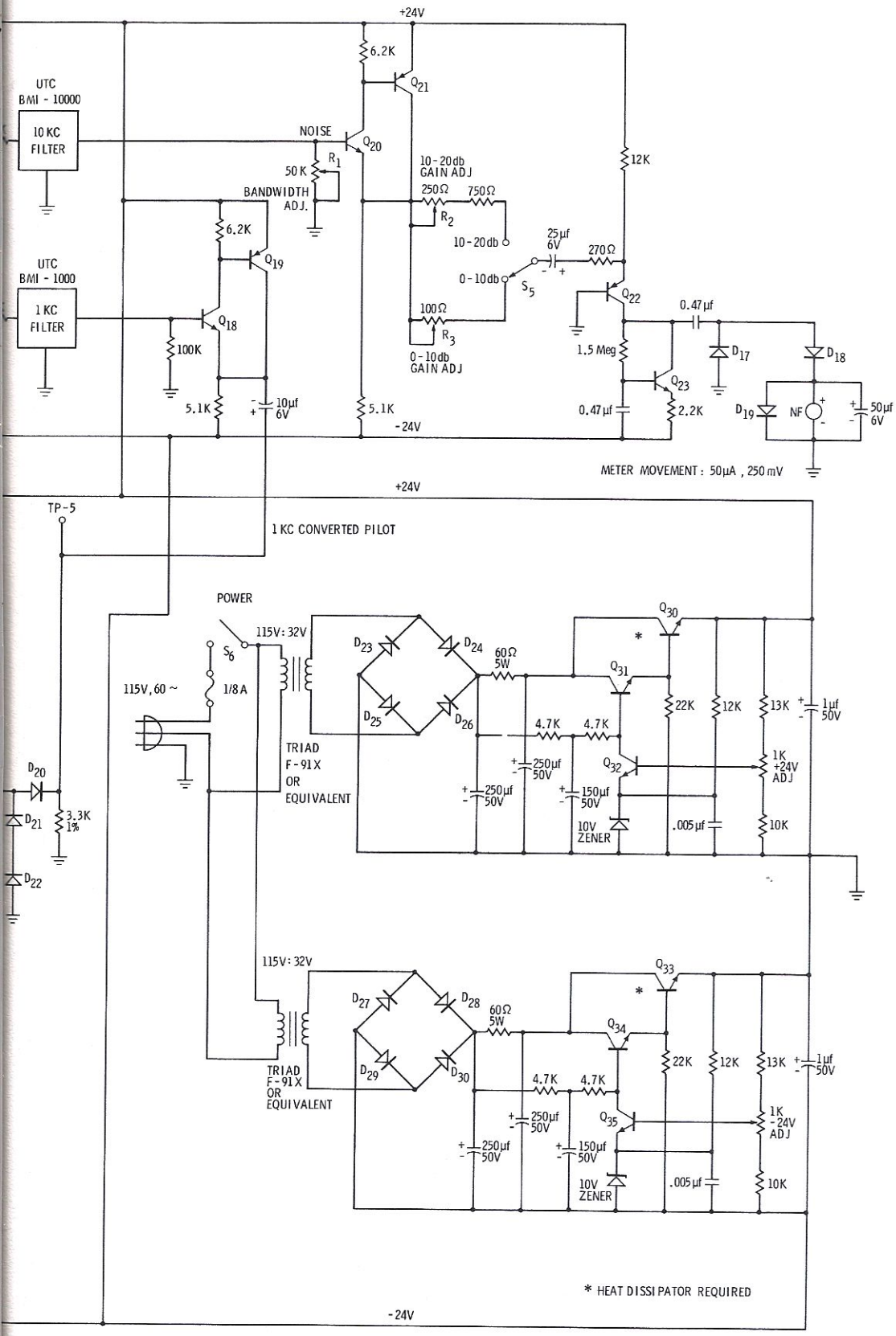


FIG. 4. Schematic diagram of 1-mc noise-figure tester.


+24V
6.2K
Q21
UTC
BMI - 10000
10 KC
FILTER
NOISE
Q20
R1
50 K
BANDWIDTH
ADJ.
10-20db
GAIN ADJ
250Ω
750Ω
R2
12K
6.2K
Q19
10-20db
25µf
6V
270Ω
UTC
BMI - 1000
1 KC
FILTER
0-10db
S5
Q22
0.47µf
Q18
100Ω
R3
0-10db
GAIN ADJ
100K
1.5 Meg
D17
D18
Q23
5.1K
10µf
6V
5.1K
-24V
0.47µf
2.2K
D19
NF
50µf
6V
METER MOVEMENT: 50µA, 250 mV
+24V
TP-5
1 KC CONVERTED PILOT
POWER
115V: 32V
S6
115V, 60 ~
1/8A
D23
D24
60Ω
5W
Q30
*
Q31
D25
D26
22K
12K
13K
1µf
50V
4.7K
4.7K
TRIAD
F-91X
OR
EQUIVALENT
250µf
50V
Q32
1K
+24V
ADJ
250µf
50V
150µf
50V
10V
ZENER
.005µf
10K
D20
D21
3.3K
1%
D22
115V: 32V
Q33
*
D27
D28
60Ω
5W
Q34
D29
D30
22K
12K
13K
1µf
50V
4.7K
4.7K
TRIAD
F-91X
OR
EQUIVALENT
250µf
50V
Q35
1K
-24V
ADJ
250µf
50V
150µf
50V
10V
ZENER
.005µf
10K
* HEAT DISSIPATOR REQUIRED
-24V